Experimental Development
Of a Special Indicator
For the Gas Engine

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EXPERIMENTAL DEVELOPMENT OF A SPECIAL INDICATOR FOR THE GAS ENGINE

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Design of a Special Indicator for the Gas Engine.

Introduction:- Of very great importance to the engineer is the steam engine indicator and yet this instrument upon which he relies so much is subject to many and often serious errors which affect in a large degree the accuracy of the results obtained.

This fact is well known and much experimental work has been carried on with a view of determining the errors that they may be allowed for or eliminated. Indeed it seems that more effort should have been spent in eliminating the errors rather than in developing apparatus of one form or another to more nicely measure those errors.

Errors of the Indicator:- The elimination of some of these faults was the object of this thesis. Let us see what the errors are and which ones we may hope to remove.

The indicator has three uses as applied to steam engines.

(a) It may be used to obtain the area of the true card as representing the work done in the cylinder per stroke.

(b) It may be used to obtain the pressure at some particular point of the stroke.

(c) Finally it may be used to obtain the shape of the true card as indicating the condition and action of the steam and the various parts of the engine."

In gas-engine parlance, the three uses would be, a) to give the indicated H. P. of the engine; b) to give "maximum pressure," "compression" or "suction pressure;" and c) to show the timing of the various events, action of valves, per cent of cylinder filled during suction, and other quantities useful in obtaining the greatest economy with any given engine.

The errors affecting the results are thus enumerated by Mr. J. Burkitt Webb ("The Comparison of Indicators;" Transactions A. S. M. E. Vol. 11, page 311, 1890.)

(1) Uniformity of the spring.

(2) Parallelism of the piston movement to the to the cylinder.

(3) Uniformity of the pencil movement.

(4) Parallelism of the pencil movement to the drum axis.

(5) Accuracy of the drum motion.

(6) Phase of the drum motion.

(7) Mass of the parts and its distribution and the strength of the spring.

(8) Friction of the piston and pencil movement.

(9) Lost motion.

In finding the work done, the accuracy is affected by errors (1), (2), (3), (5), (6), (8), and (9), of which (1), (3), (5) & (9) may be allowed for.

In general, (2) alters the area; (6) tends to reduce it; and (8) when produced by (2) increases it; (7) acts indirectly through (5) and (6).

For finding the pressure at some particular point of the stroke the accuracy is seriously affected by errors due to (5) and (6) for the pressure is measured at apparently the correct point but not actually so. In the gas engine the errors due to these causes are not of great moment as it is the pressure that is sought and but little attention is paid to the point of the stroke where it occurs.

In the indicator under consideration the statement of (4) & (5) will be changed and (6) & (7) eliminated: (4) will read, " Coincidence of the pencil movement with a radius of the disk", and (5) will become,- " Accuracy of the disk motion."-

In regard to the value of the errors, Mr. D. S

Jacobus,(" A Comparison of the Mean Ef[illegible]
of Simultaneous Cards taken by Different Indicators," Transactions, A. S. M. E. 1894. Vol. 15: page 277) draws the following conclusions as the result of some tests on a steam engine with horizontal cylinder 7 inches in diameter and 14 inch stroke, running at 175 to 200 revolutions per minute.

(1) The errors are no greater than that occurring in measuring the hot scales of their springs.

(2) A leaky piston is much more reliable than one that is too tight a fit.

(3) The greatest error for the mean effective pressure of cards at 25 per cent cut off was 0.9 per cent in 4 indicators tested.

Nine-tenths of one per cent is not large but it must be remembered that with a gas engine at 300--1200 revolutions per minute the error becomes rapidly greater and the indicator becomes practically worthless when 400 revolutions per minute is reached.

Mr. Webb, in the article referred to, gives a hint at an indicator such as the one used. He says,--" I believe however, that for accurate work it might be better to run an indicator drum continuously by a belt

from the engine shaft and to get the area of the card by adding together a sufficient number of ordinates, so spaced as to allow for the change in the card due to the change in the motion of the drum." "--- planimeter work is not in general so accurate as the method by ordinates."

This was one of two references that showed research along the line of this thesis; the other was in regard to a recording indicator invented by Mr. Wm. F. Lloyd. (" An Improved Engine indicator;" Scientific American; Apr. 14th. 1906.) But here errors are added instead of subtracted. The inventor has a light disk driven by a cord attached to the crosshead of the engine or to the reducing motion. The motion is therefore reciprocating. Across the face of the disk is a vertical shaft on which is splined a light pulley of the form used in planimeters. The pencil motion ends in a yoke that moves the wheel referred to in or out with reference to the center of the disk. The shaft has a worm at the upper end and which acts upon a gear and train of dials so that the reading of the dial times the diameter of the cylinder gives the horse-power developed in the interval of time. Here the reciprocating disk

is retained in place of a reciprocating drum and the inertia of the wheel and its friction on the shaft is added to the already too long list of errors.

In the present indicator, the drum is dispensed with and a light aluminum disk 4 1/2 inches in diameter is used instead, as shown at Plate 1 (A). The indicator proper will be recognized as a Crosby Indicator. It has a piston of 1/4 of a square inch area and is intended for gas engine work. The drum was removed and a brass casting (B) made which clamps the barrel of the indicator and provides journals for the shaft carrying the disk. This shaft is of steel 1/4 inch in diameter at the bearings and 5 1/16 inches long over all. A brass nut is provided to hold the card in place and a pulley 3 9/16 inches in diameter to drive the disk. The indicator was designed for use on a Fairbanks Morse 7 horse power gas engine and the long shaft was used to give the off-set necessary to clear the cranks. Indeed on almost any gas engine as much more or more off-set is imperative for similar reasons. A clutch is provided so that the disk is stationary except when a card is being taken. Pressure on the button at the end of the shaft causes the pin to bind the revolving pulley and the collar on the shaft together and the disk is set in motion. There are some

flaws in this construction but they will be mentioned later.

Since the Fairbanks engine was of the " hit or miss" type and the work done in successive strokes varied widely, it was decided to experiment with the three cylinder Westinghouse engine, indicating the center cylinder only. Accordingly a split pulley of maple was made, 3 9/16 inches in diameter with a groove for the twisted rawhide belt that was used. This pulley was placed on the inlet cam shaft and fastened by binding wires around the hubs. A card taken at this time is shown at (A) Plate VI. It is seen that the card did not retrace owing to slip of belt or incorrect diameter of driving pulley. The card was taken while rotating in a counter clock-wise direction and at one-half the speed of the engine so that the complete cycle of events is represented by one revolution.

At this time the problem of an easy means of finding the mean effective pressure came up for solution and after some study was temporarily dropped. As the problem would not be complicated by driving the indicator at engine speed and the events of the card would be strung out over greater arcs, it was decided to make a larger split pulley 7 1/8 inches in diameter and thus increase the speed of the indicator 100 per cent. A

sketch of this pulley is shown on Plate II, (A and B) where it will be noticed that provision is also made for driving at 1/2 engine speed in case that seemed more desirable after a trial of the other speed. This pulley was a great improvement over the other, being held together by screws, and having grooves of various diameters. It was found that the largest groove was not quite large enough, so it was shellaced and a second layer of paper used as a bushing. Grooves 4 and 5 were now nearly correct but not entirely so. Cards 1, 2, 3, and 4, Plate VII, show how nearly the cards retrace for the various grooves.

One precaution has to be observed however in taking these cards. The button of the clutch revolves when the indicator is working, resulting in friction between the button and the means by which it is pressed in. Cards were taken with tight and loose belts and varying friction at the clutch. From these it appeared that a tight belt is less affected by varying friction than a loose one. This is shown on card 5, Plate VII. The variable friction was secured by using successively as the means of holding in the button of the clutch; the fore part of the first finger, the end of the same and

the point of a lead pencil. In a final design, it would be better to have a clutch that can be thrown in or out of gear and leave both hands free to manipulate the pencil movement and the indicator cock.

From a pulley with a number of grooves it was but a step to a conical pulley as a means of securing the correct diameter of driving pulley to cause the card to retrace. A loop of wire held by a nut of the cylinder cover was found an adequate means of guiding the belt to any part of the pulley. The pulley consisted simply of a disk of poplar glued to the grooved pulley as shown at (C) Plate II. A point on this pulley was readily found where the card was retraced as often as desired. For experimental purposes where a positive chain drive is not practicable, we would recommend this form of pulley as the simplest and surest way to make the card retrace. Cards taken at various points of the pulley in the process of finding the proper point are shown in Plate VIII, Nos. 1, 2 and 3. Card No. 3, has not been excelled by any card taken with positive chain drive. In taking these cards however, constant friction at the clutch had to be secured by the use of a pencil

as stated above.

The question must have arisen in the mind of the reader as to how some point of the cycle is established as a reference point on the card from which to measure the timing of the various events of the cycle. After a consideration of various ways, an electrical device was decided upon. An induction coil was secured of such size as to give a 1 ½ inch spark with one double cell of storage battery. One end of the secondary was connected to a convenient point on the engine frame; the other to a pointed steel wire held by the hard rubber insulator shown at C, Plates I and IV. The other connections are shown in diagram on Plate IV. In order to have but one spark pass from point to disk per revolution, the interrupter was cut out by placing paper between the contact point and the armature; the primary circuit was then broken by means of a circuit breaker on the engine shaft. This consisted of a ring of maple 5 inches in diameter and 1 1/4 inch face. Two shallow grooves 1/4 inch wide were turned in the periphery and brass rings fastened in these in a fitting manner. One of these was a complete circle; the other an arc of some

20 degrees. The two were cross-connected as shown and provided with brushes held in a suitable holder on the engine frame. By means of a surface gage on the piston of the center cylinder, the pin was set at such a point that the current was broken when the crank was on the upper dead center. Although but one cell was used, the brush and arc of brass burned away and the collar had to be re-set occasionally. Two cells were tried in order to have a larger hole pierced and to do away with an error caused by the blowing of the spark from its course by the wind of the rotating card. The latter difficulty was diminished but the arcing was excessive. By means of the reversing switch, the direction of the spark could be changed and the above error was less for one position than for the other. As far as could be determined it was less where the spark passed from the disk to the point. This seems the more reasonable view and the actual direction could not of course be judged by the hole punctured nor determined with certainty [illegible].

This apparatus need not be included in a final design involving positive chain drive for then a mark can be made on the disk indicating the dead center and a line made across one half of the card by [illegible] the

indicat[illegible] with the disk stationary at the proper point. In such case there must be no slipping of the clutch on the shaft and the disk must be keyed on. Neither of these conditions prevailed in the present indicator. The disk was not keyed on at the first but was so treated later because it turned on the shaft in a clock-wise direction due to its inertia at starting. This made the nut holding the card bind so tight as to be difficult of removal. The collar too was fastened by a single set screw pressing upon the 1/4 inch shaft in which, as will be seen in Plate I, there is a 3/16 inch hole. Some trouble was experienced with this collar slipping: at the higher speeds current in automobile work it would be sure to do so and some other form of clutch should be used that would give a gradual acceleration to the disk.

While speaking of the present clutch another fault may be mentioned. There is a play in the clutch equivalent to some 2 degrees on the disk, due to the looseness with which the pin fits into the hole. This is partly due to faulty construction and partly to the fact that there must be some play in order that the pin may enter easily. We would suggest a tapered pin in a

to write [illegible] in a better design, [illegible] r [illegible]-in of such magnitude that the pin would not bind when pressed in.

The next step in the experimental work was the design and installation of a positive drive. Bevel gears with telescoping shaft were considered but finally rejected as being rather intricate. A light roller chain of 1/4 inch pitch and 1/8 inch tread was at last secured and sprockets designed having 24 and 48 teeth in accordance with the formulae on page 277 of Brown & Sharpe's catalogue (1908). The calculations are as given below:-

N--Number of Teeth in Sprocket------------24.-------------48.

P--Pitch of Chain,(inches)----------------.25-------------.25

D--Diameter of Roller, (inches)----------.110-------------.110

A--180 degrees ÷ N, (degrees--------------7.5-------------3.75

Pitch diameter = P ÷ Sin. a, (inches) 1.915----------3.8[illegible]

Outside Diameter= Pitch Diameter + D(inches)--

[illegible].02[illegible]--------------4.03[illegible]

Bottom Diameter=

Pitch Diameter— D(inches) - 1.805-------- ---3.813

The patterns for these sprockets were made by the writer and the gears cast in yellow brass at the Institute. The sprockets were machined up and delivered

to them, and set screws put in them. The larger one was bored and reamed for a 1 3/16 inch shaft and the smaller for a 7/16 inch one. As the bearing of the latter is of brass, a cast iron bushing was fitted in the sprocket so as not to have brass rubbing on brass. When the chain was in place it was found that its weight was sufficient to turn the indicator in its cock and so a wire was stretched to a convenient point to furnish a pull in the other direction. But some slack was necessary for the easy running of the chain and as was expected this allowed some 2 degrees of play in the movement of the disk. This could be overcome in a large degree by an idle pulley and one should be included in a final design.

We have now seen the development of the indicator from one with a twisted rawhide belt drive to one with positive chain drive and electrical device to indicate the dead center points. No method of finding the mean effective pressure has been found involving the use of a planimeter. But there is no reason why a planimeter should be used except that it is a rapid and easy means to an end. It cannot be used in this case because the motion of the disk is uniform while that of

the piston is harmonic, that is, the phase is not the same. The method involving the use of ordinates can always be resorted to and so to facilitate the choice and measurement of ordinates, a thin piece of transparent celluloid was prepared as shown in Plate V. To diminish the errors in drafting, the stroke and crank circle was laid off of large size, about 6 inches diameter and divided into thirty equal parts. Ordinates erected at these points give the corresponding crank positions, no allowance being made for angularity of the connecting rod. This should certainly be taken into account and so a system of templates should be prepared for various ratios of crank and connecting rod. In the present case this is 1 to 6, and the template was made with an allowance for this amount.

To compare the cards taken with those from an indicator of usual form, the indicator cock was replaced with a tee and two elbows into which were fitted two indicator cocks. In these were mounted the special indicator and one of ordinary form (Crosby #8016) as shown in the photograph of the engine and experimental apparatus on Plate IX. All was now in readiness to make the final runs with various settings of valves and ignition. These were made and will be described in

a[illegible] appendix to this thesis. [illegible] a[illegible] of the sensitivi-
ty with which small changes are shown by this indicator, the cards 4, 5, and 6, Plate VIII, are submitted. Here the nut on the igniter trip stem was turned a few times giving more clearance and slightly later ignition. The effect of this slight change is shown very clearly on the cards, by a later and smaller maximum pressure.

The cards can be readily made by clamping squares of paper between two wooden disks 4 1/2 inches in diameter, one disk being screwed to a face-plate; the other being held in place by a screw through the 1/8 inch hole previously bored in the squares. A sharp skew chisel held parallel to the bed of the lathe quickly removes the corners and leaves the cards with a smooth edge. For constant use, the cards should be of slightly heavier paper than the sample shown as these developed a tendency to ride up in front of the pencil.

Summing up some of the points to be observed in the final design we would recommend:-

1.) That the disk have a longer hub, more closely fitting the shaft. In the present indicator the hub was but 3/16 inches long and rather a loose fit so that it did not always run perfectly true.

2.) The disk should have a smoother, harder

surface. [illegible] recom[illegible], [illegible] heavy disk of brass with nickeled face can be used.

3.) A clutch should be designed that will accelerate the disk gradually. This can be done by having a collar keyed to the shaft and held by a set screw. Through this collar should pass the connecting pin, enter into a hole in a second collar loose on the shaft but connected to the revolving sprocket by a spiral spring. In one or two revolutions the disk would be accelerated to the speed of the sprocket and the pin be pushed into a hole in the sprocket itself binding it rigidly to the collar. The hole in the sprocket and the end of the pin could be made a taper fit as suggested above.

4.) An idler pulley should be provided to keep the chain fairly tight and yet allow easy running.

5.) The [illegible] the card against the disk is [illegible] split spring [illegible] its removal [illegible] conditions. Without such an improvement, [illegible] the [illegible] of cards is more rapid and simple than in the other form of indicator. [illegible] after starting the indicator.

6.) The [illegible] castings of the [illegible] indicator and the barrel can be made in one piece making a better construction.

Our experiments with this indicator have convinced us that it possesses decided advantages over the older forms in showing the sequence of the events. What idea does the statement convey that the inlet valve opens 5 degrees late, when a rectangular card is being examined? On the circular card, however, at about 8 degrees after the upper dead center the line representing the exhaust back pressure begins to drop to the level of the suction pressure and a statement of "degrees" means something.

The inertia of the pencil movement, the friction of the piston, and the lack of uniformity in the spring are not obviated in the present design; but much has been accomplished, we believe, in diminishing the errors of the indicator and in extending its field of usefulness into the realms of gas engine and rotary steam engine work. Even if the speed is higher in automobile engines and the events follow faster, the time of combustion and consequent rise in pressure cannot be greatly hastened or the errors due to the inertia of the pencil movement greatly augmented. The speed at which the disk may be driven is almost unlimited.

Respectfully submitted,

Chicago, Ill
June 4, 1906.

Wm. E. Brubaker

Appendix to Thesis.--

Design of a Special Indicator for the Gas Engine.

Final Tests of the Indicator:-

As stated in the body of this thesis, runs were made under various conditions to prove or disprove the value of the indicator in showing more clearly the succession of events. These tests may be classes thus:-

I. General test.- Normal settings.

a.) Earlier
1. Inlet
b.) Later.

II. Valve changes.

a.) Earlier
2. Exhaust
b.) Later.

III. Ignition changes.

The engine is a three cylinder vertical Westinghouse gas engine, with cylinders 8 inches in diameter and 10 inch stroke. It is rated at 40 Indicated Horse Power at 300 revolutions per minute but easily carries an overload of 40 Brake Horse Power. It is of four cycle pattern and is clearly shown in Plates XV and XVI, which give front and rear views respectively.

For these runs natural gas from the city mains was used, having an effective calorific value of about

910 British Thermal units per cubic foot, as determined in the course of previous tests. The average proportion of air and gas was about 10.8 to 1.0, corresponding to gas and air mixing-valve settings of 0.37 and 4.0 respectively. Under normal setting of valves the work is divided very equally among the three cylinders, as they all have about the same clearance. Thus,--

Clearance:-

Left,-----106.81 cu. in.------21.25 percent.
Center,---100.53 cu. in.------20.00 percent.
Right,----109.95 cu. in.------21.87 percent.

Other constants of the engine are,-

Length of Brake Arm,--63.5 inches =5.29 feet.
Dead Weight of Brake Arm,-----16.5 pounds.
Weight of Strut,------------- 6.5 pounds.
Total Dead Weight on Scales---23.0 pounds.

I. General Test.--

A run of 80 minutes duration was made under normal setting of valves and ignition, gas-meter readings being taken every five minutes. The load was 125 pounds gross or 102.0 pounds, net. A short run had been made previously under a gross load of 50 pounds or net load of 27 pounds.

The brake horse power equals

$$B.H.P. = 2\pi R \div 33{,}000 \times NP$$

where R = radius of the brake arm, in feet.

N = revolutions per minute.

P = net load on the scales, pounds.

Therefore,-

$$B.H.P. = 2\pi \times 5.2917 \div 33,000 \times NP.$$

$$= 0.001007\ NP.$$

$$= 0.001007 \times 310 \times 102 = 31.85\ H.P.$$

With a range of speed of 296 to [illegible] revolutions per minute during the run, the average horse power was 31.13 H.P., which is seen to be somewhat less than the full power of the engine. The brake horse power for the run at 50 pounds gross load was 8.16 H.P. The indicated horse power was 40.3 and 15.5 I.H.P. giving mechanical efficiencies of 77.3 and 52.5 percent for heavy and light loads.

The gas consumption for the run was 583.8 cubic feet, (uncorrected for temperature and pressure); or 14.0 cubic feet per brake horse power per hour. Cards were taken on both indicators during these runs and typical ones are submitted on Plate XVII.

II. 1. Inlet Valve Changes:-

The inlet valve setting was changed by moving the inlet-cam shaft forward or back by one tooth in the larger bevel gear at the left end. As there are 48 teeth in this, the change in the event was 1/48 × 720 de-

grees or 15 degrees, since this runs at half the speed of the main shaft. In setting the inlet valves earlier than normal, the ignition was also changed by the rotation of the shaft and had to be set back to the normal point on all three cylinders. For late inlet events the ignition of the center cylinder only was set forward to normal, the others being but 7.5 degrees early. (Normal ignition is 22.5 or 30 degrees early.)

Cards taken with earlier and later setting than normal are shown on Plate XII. These are to be compared with the normal cards, 3 and 4, a---d, Plate X. The crank angles at which the various events take place are stated in tabular form on Plate XIV. Normally, the succession of events is this,--

Ignition,-- Working stroke.

Exhaust opens,-- Exhaust Stroke.

Exhaust closes and (6 degrees later),

Inlet opens,-- Induction or Suction Stroke.

Inlet closes,-- Compression Stroke.

This succession is well shown by the diagram of Plate XVIII, where the two circles representing the two revolutions of the cycle are slightly separated for the sake of clearness. The most work is done during the working stroke, therefore it is represented by the longest line:

negative work is done during the induction stroke; there fore a short line. The normal events are indicated by an arrow-head; the changed ones by stars.

It will be seen that for the earlier inlet setting, the inlet opens before the exhaust valve closes permitting exhaust gases to be driven back into the mixing chamber. This seems undesirable because of the danger of back firing from the hot gases, but such a condition is advised in the "Instruction Book" accompanying the engine.

The later inlet setting causes an undesirable condition, namely, a vacuum in the cylinder due to the late opening. This is shown by the rapid drop to full suction pressure (on cards 13, c, and 14, c,) immediately after the opening of the valve. This difference is more marked on the heavy load cards(4,c, and 13,c,) than on those for light load, (3, c, and 14, c,)

II, 2. Exhaust Valve Changes.

The exhaust valve changes were effected in the same way as the inlet, that is, by moving the gear on the end of the shaft one tooth forward or back. There are 54 teeth on this gear and it meshes with one having 27 teeth and turning at engine speed. A change of one tooth is therefore equal to a change of 1 /54 x 720 or 13.3 degrees on the card. By actual measurement on the

fly wheel the change varied from 14 to 18 degrees. Usually such a measurement can be taken to within two degrees as seen in all other cases during these tests.

A change in the exhaust valve, either early or late, seems to have but little effect as far as the opening of the valve is concerned, but has a decided influence as regards its closing. When set late, it is open for 13 degrees while the inlet valve is also open, producing the same effect as early inlet. When set earlier it closes 18 degrees before the upper dead center and as the inlet does not open till 3 degrees late, there is a compression of the gases just before suction begins, as seen in cards 15 and 16, a---d.

Upon the opening of the inlet valve these gases are driven into the mixing chamber, an undesirable feature, to say nothing of the work lost in compressing them.

III. Ignition Changes.

The effect of changes in the time of the ignition is shown on Plates X and XII. With the inlet and exhaust valves set normal, the time of the ignition was varied from 45 degrees early to 15 degrees late on the center cylinder, the others being at 22.5 degrees throughout.

At 45 degrees early, pounding was noticeable and the tee of the indicator connections became a dull red. The pressure in the center cylinder rose as high as 300 pounds per square inch on the heavy load. Vibration of the indicator, inertia of the pencil motion, or some other influence caused the jagged appearance of the card shown, the effect being less marked on the rectangular card. Even with the ignition at 30 degrees early, the same behavior is apparent.

The ignition is changed by shifting a toothed collar on the inlet cam shaft. There are 96 teeth, so that a change of one tooth represents 1/96th of 720 degrees on the card, or 7.5 degrees. The changes were then 45, 30, 22.5, and 15 degrees early and 8 and 15 degrees late. (Evidently the "8" should have been read "7.5" degrees.)

In general, it would seem from cards 1,c, to 10,c, that the drop at exhaust is more sudden for heavy loads than for light, due to a greater charge and consequent high pressure. It also takes place at later points; and furthermore, the exhaust takes place at greater intervals after the valve opening as ignition is set later and later. True, such an effect is shown

on the rectangular cards 1,d, to 10,d, but not so clearly nor are they evident with as little inspection.

Another interesting use to which these cards readily lend themselves is the calculation of the time required for combustion. The point of ignition is known with fair accuracy and the angle between it and the maximum pressure can be readily measured. The speed is known and the time represented by the angle is easily calculated. For example, --

Let A represent the angle and R the revolutions per minute. Then $\frac{60}{R}$ equals the time required for one revolution; in seconds and $\frac{A}{360}$ equals the fraction of a second embraced by the angle. The time of combustion therefore

$$t = \frac{60}{R} \times \frac{A}{360} = \frac{A}{6R}$$

The measurements are as follows:-

Load.	Card.	Angle, A	Speed, R	Time, t.
Light	1a	70	306	0.0358
Heavy	2a	53	294	.0300
L.	3a	60	300	.0333
H.	4a	50	298	.0280
H.	5a	60	304	.0329
L.	6a	70	312	.0374
H.	7a	50	286	.0291

L--- 8a---------70-------------300-----------------.0390

H----9a---------60-------------296----------------- .0296

L---10a---------75-------------316-----------------.0395

H---11a---------49-------------302-----------------.0264

L---12a---------62-------------308-----------------.0330

H---13a---------40-------------306-----------------.0218

L---14a---------49-------------302-----------------.0264

H---15a---------50-------------310-----------------.0262

L---16a---------55-------------314-----------------.0291

H---17a---------45-------------306-----------------.0234

L---18a---------60-------------310-----------------.0327

It will be noticed that the time of combustion is less for heavier loads than for light. Averaging the times separately, we obtain 0.034(04) seconds as the time under light load, and 0.027(5) seconds for heavy. The time from ignition till the maximum pressure occurred has been called the time of combustion. This, of course is simply assumed and may not be absolutely correct but is sufficiently so for the present purpose.

Some special cards are given on Plate XIX. The igniter wire was removed for cards 19,a---d, which were taken at full speed; and the switch was opened till the engine had almost stopped, when cards 20,a---c were

taken and the switch closed again before a complete stand-still occurred. A 20-pound-stop card was taken for slow speed and destroyed as having no value. It was of about the form shown in dotted outline at 20,d.--

The differences in the two sets of cards are therefore only those due to the inertia of the indicator parts or of the gases themselves. Card 20,b, is the one usually taken for the " maximum compression" of the engine; 20,a, corresponds to it on the new indicator. 19, c, and 20,c, give the percent the charge is of the cylinder volumn, exclusive of clearance. Thus, scaling off from the cards the maximum compression is 1.33 inches or 106.4 pounds on an 80 pound spring and the percent as noted is $\frac{af}{ac} = \frac{1.26}{3.[illegible]} = 42$ percent.
Allowing for a clearance of 20. percent of the cylinder volume, or .6 inches on a 3-inch card, the volume of the charge is $\frac{1.[illegible]}{3.6[illegible]} = 51.6$ percent of the total cylinder and clearance volume.

For obtaining a similar quantity on the circular card, the point (d) must be found by striking the arc (bd) with a radius equal to three times the diameter of the atmospheric circle.

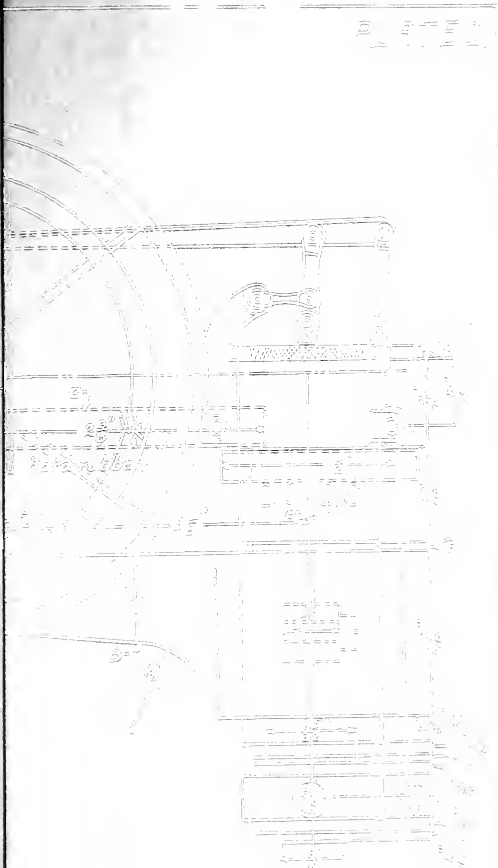
Then $\frac{cf}{ac}$ = the percent of the charge, no allowance for clearance, or 44.2 percent. Allowing for

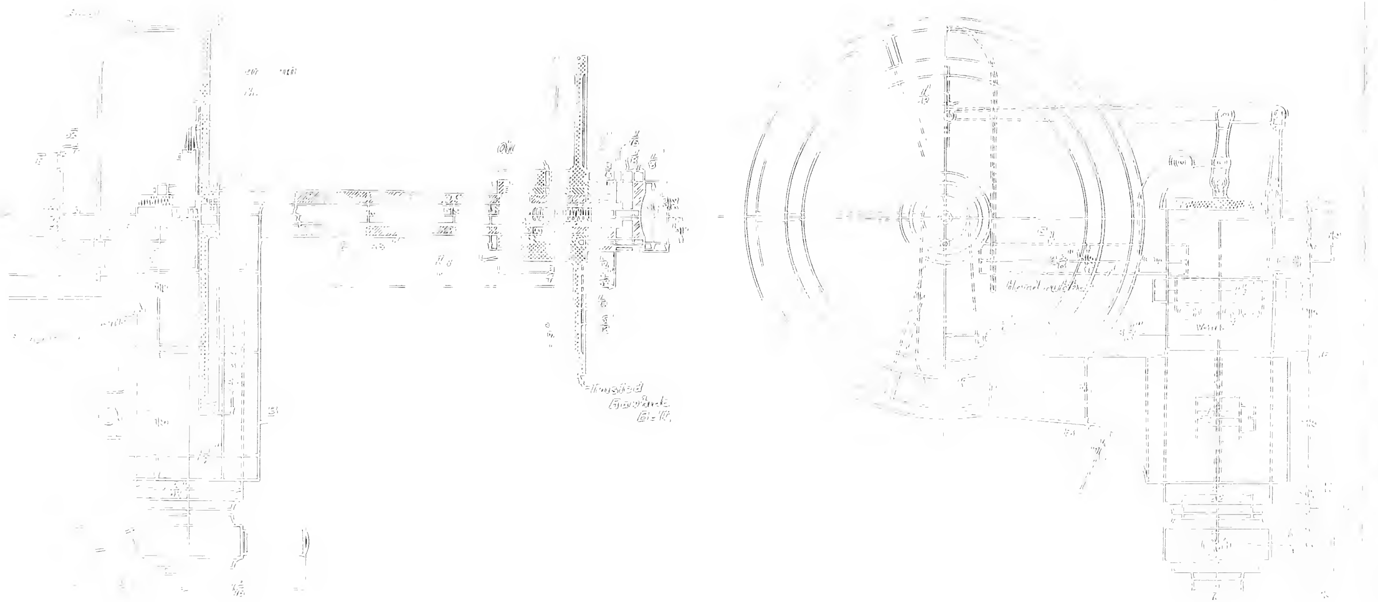
clearance, it becomes 63.1 percent.

With the exception, then, of the difficulty encountered in calculating the power developed as shown by the card, this indicator possesses marked superiority over the other forms for gas engine work and all high speed engines whether gas or steam. The calculation of the power even with the use of the template is a very tedious process. Some mechanical means may be found for doing this but has not thus far been hit upon.

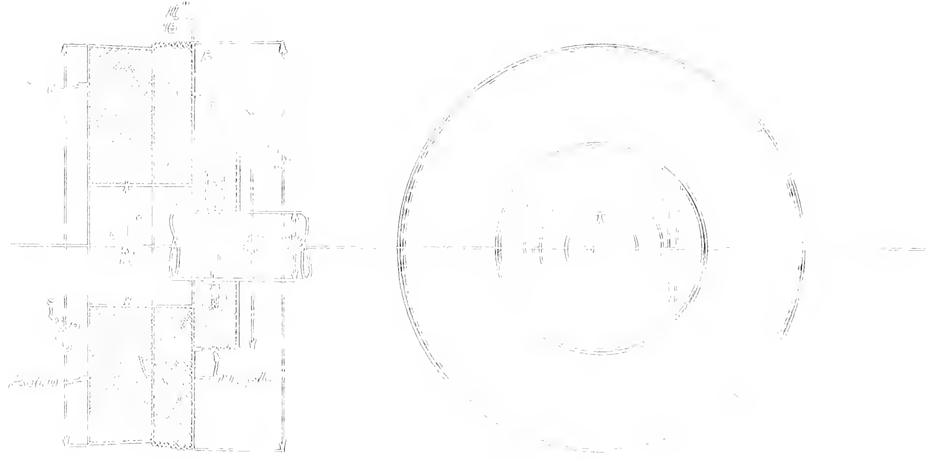
Chicago, Ill.

June [illegible], 190[illegible].

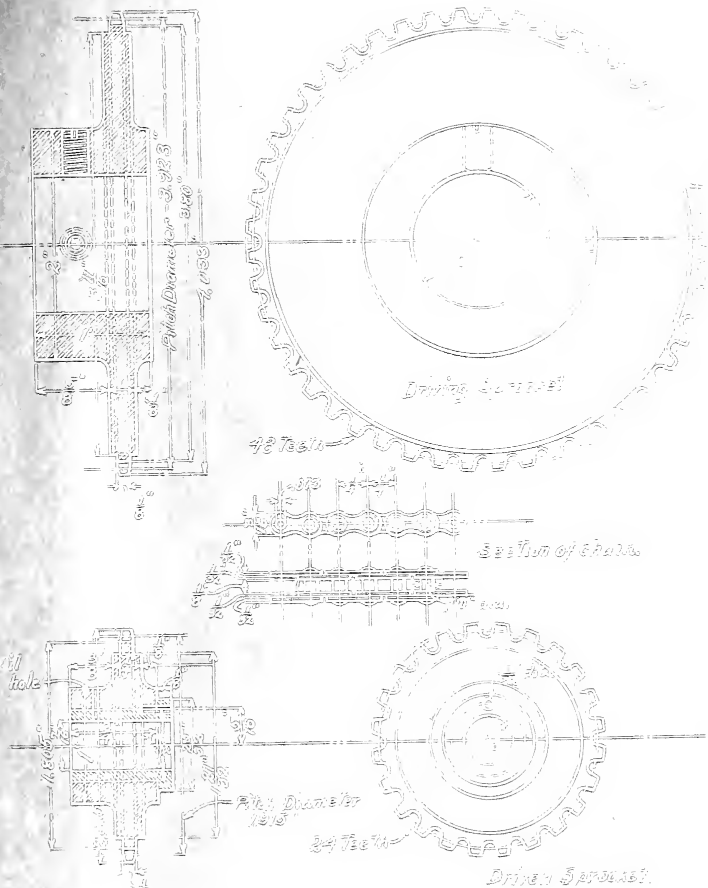




... CLUTCH FOR THE GAS ENGINE.



Experimental Drawing



Sprockets for driving Special Gas Engine Indicator

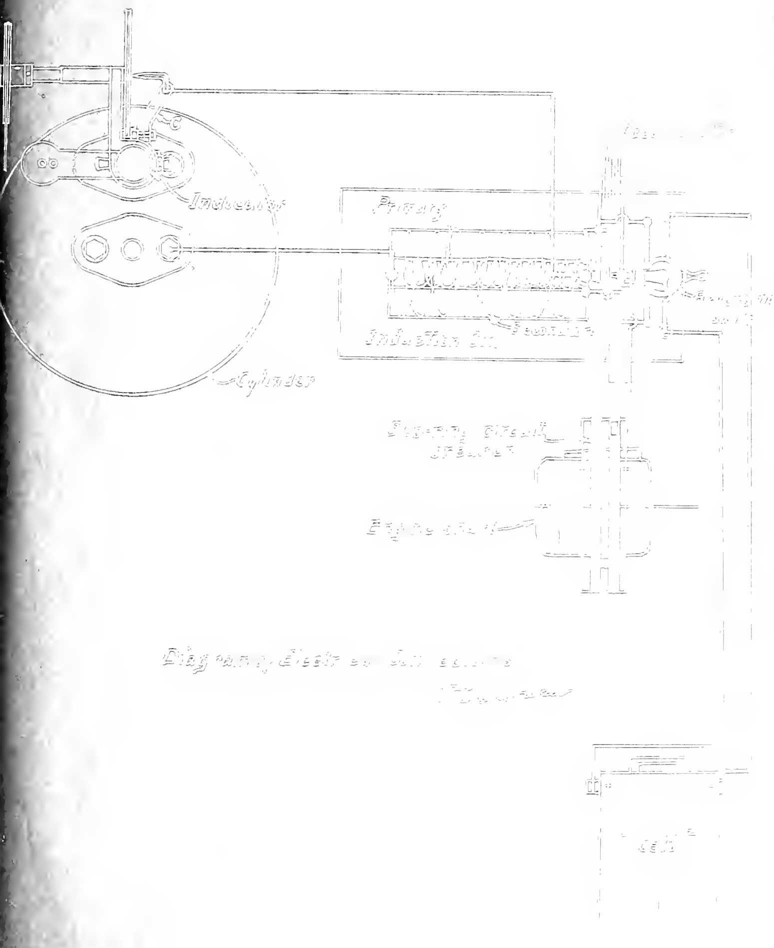
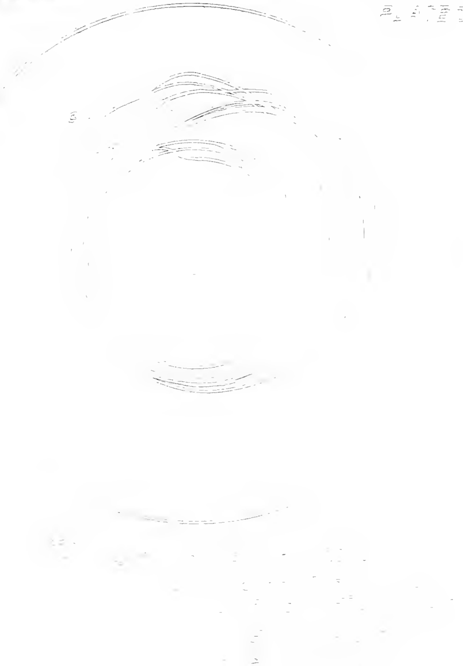


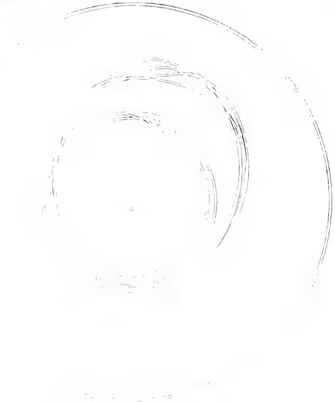
Diagram of Electrical Connections

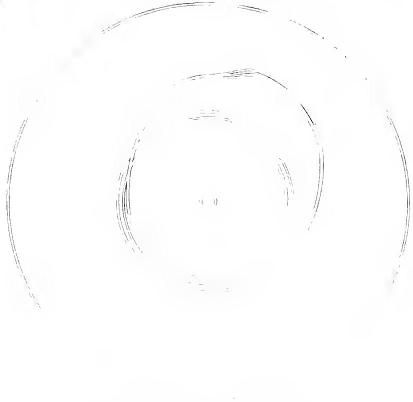
PLATE VI.

Wm. E. Brubaker.

PLATE [illegible].







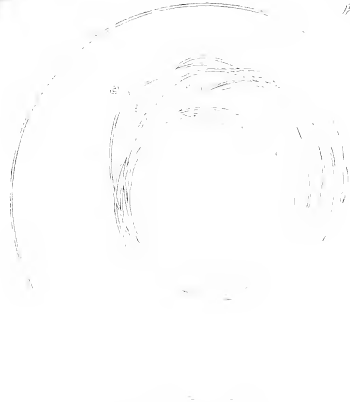
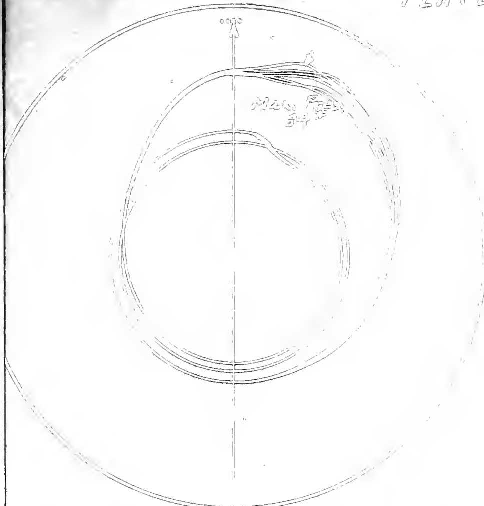
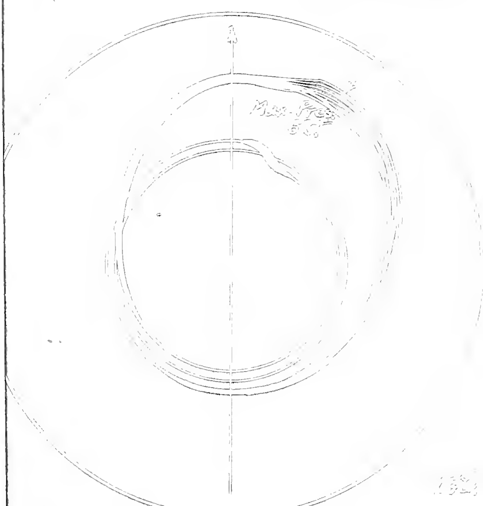


PLATE VIII.

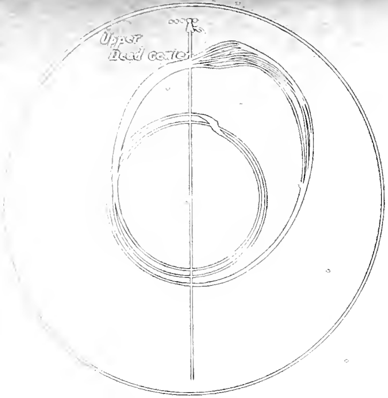


#5. May 4, 1906. 80# Ignition still later than #4.

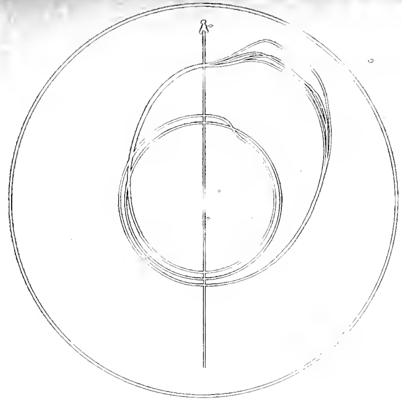


#6. May 4 1906. 80# Ignition still later than in #5.

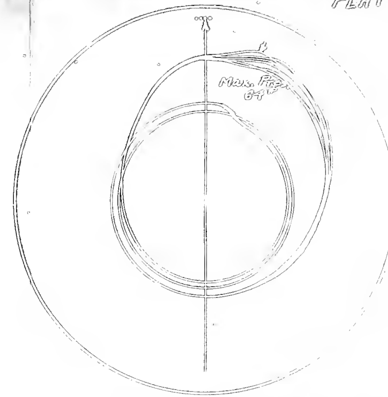
PLATE VIII.



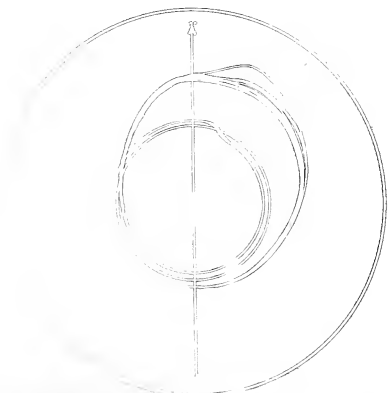
#1. Conical Pulley #3 May 7, 1906. 80#



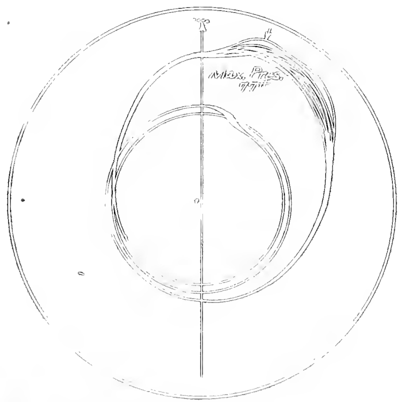
#3. Conical Pulley #8. May 7, 1906. 80#



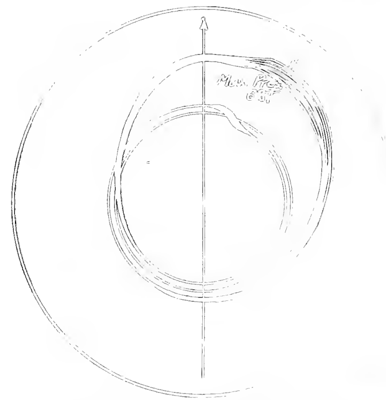
#5. May 4, 1906. 80# Ignition [illegible] later than #4



#Conical Pulley #4. May 7, 1906. 80#

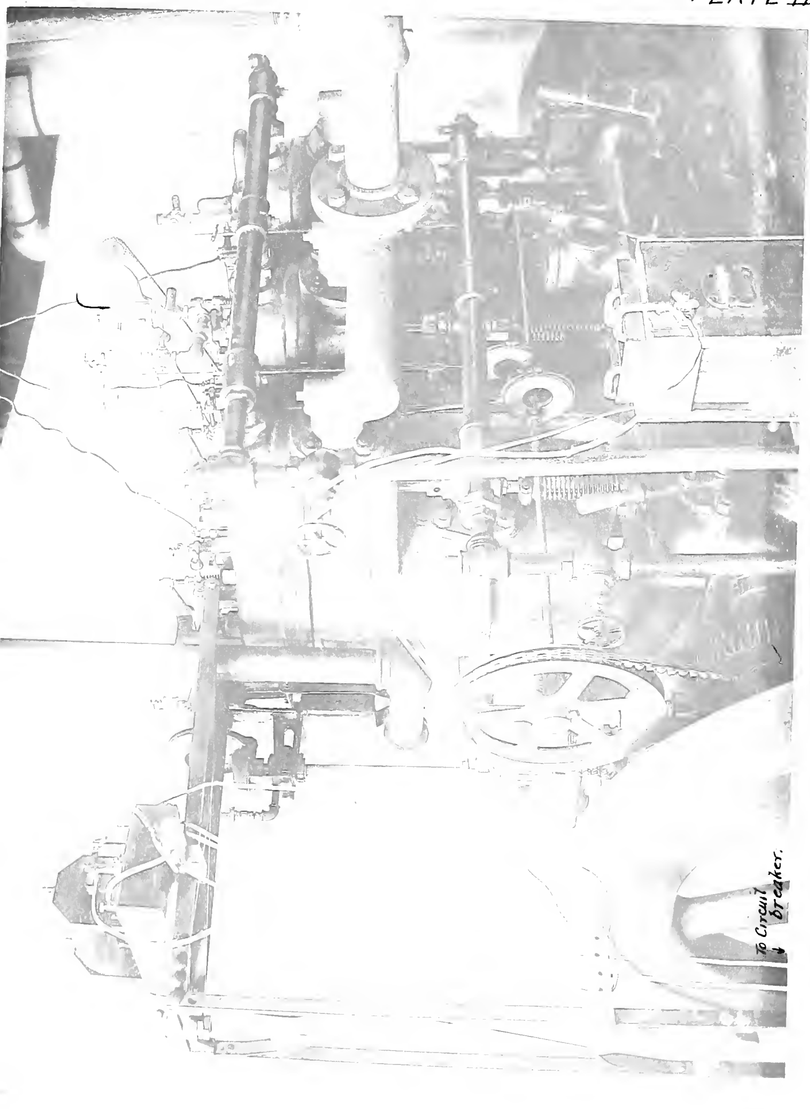


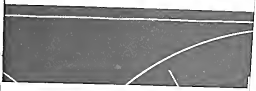
#4. May 4, 1906. 80#



#6. May 4, 1906. 80# [illegible]

PLATE IX.





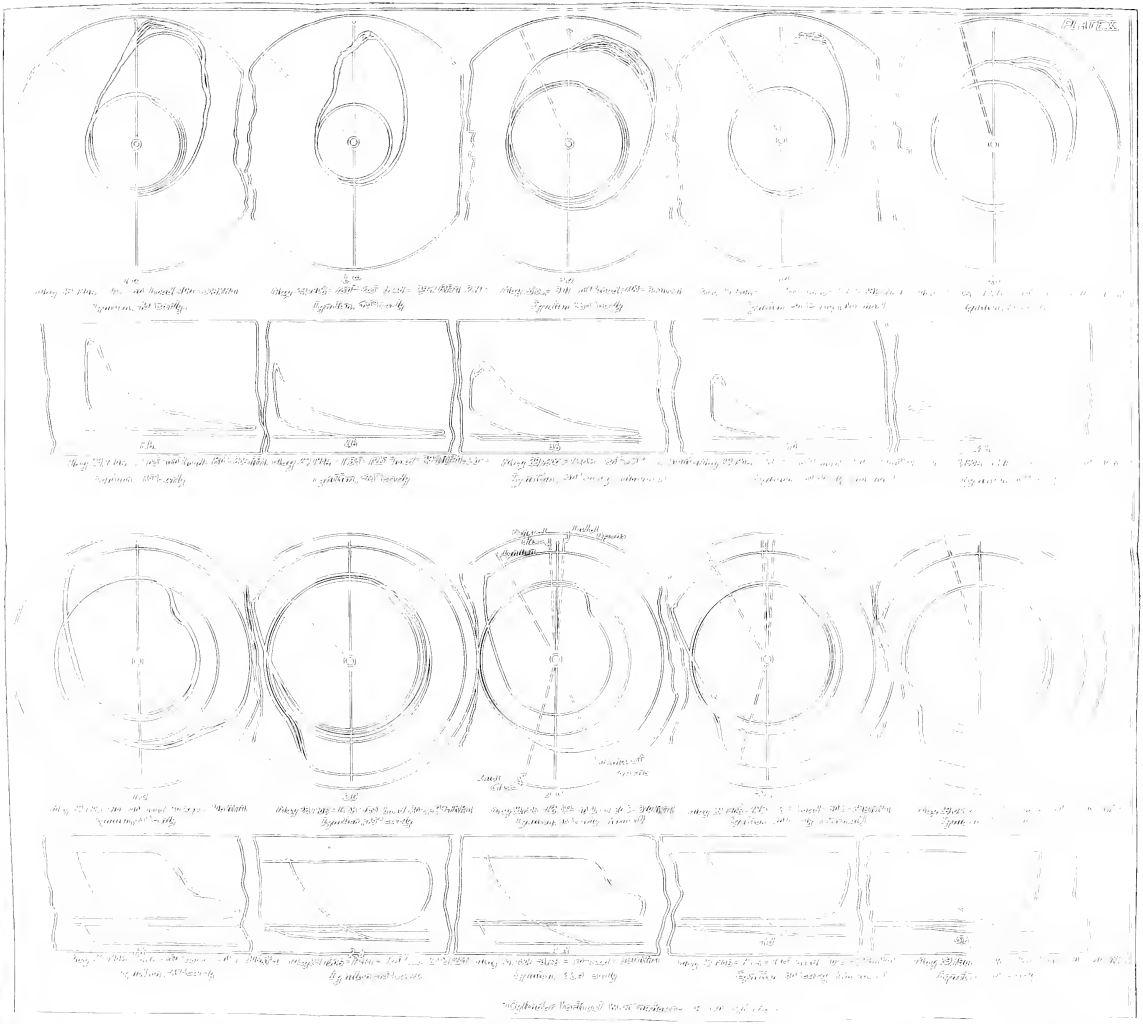
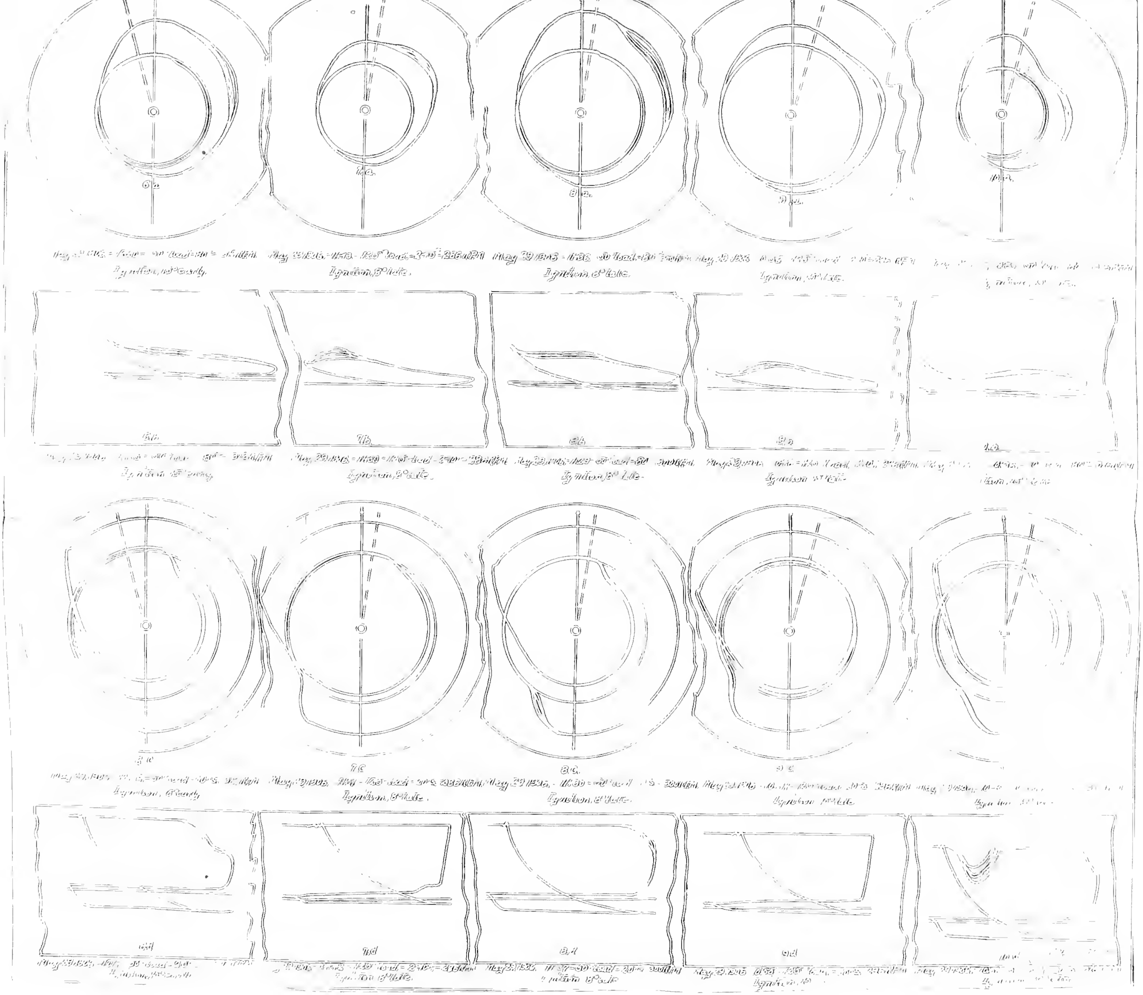


PLATE X.

XIV

PLATE XI




XIV

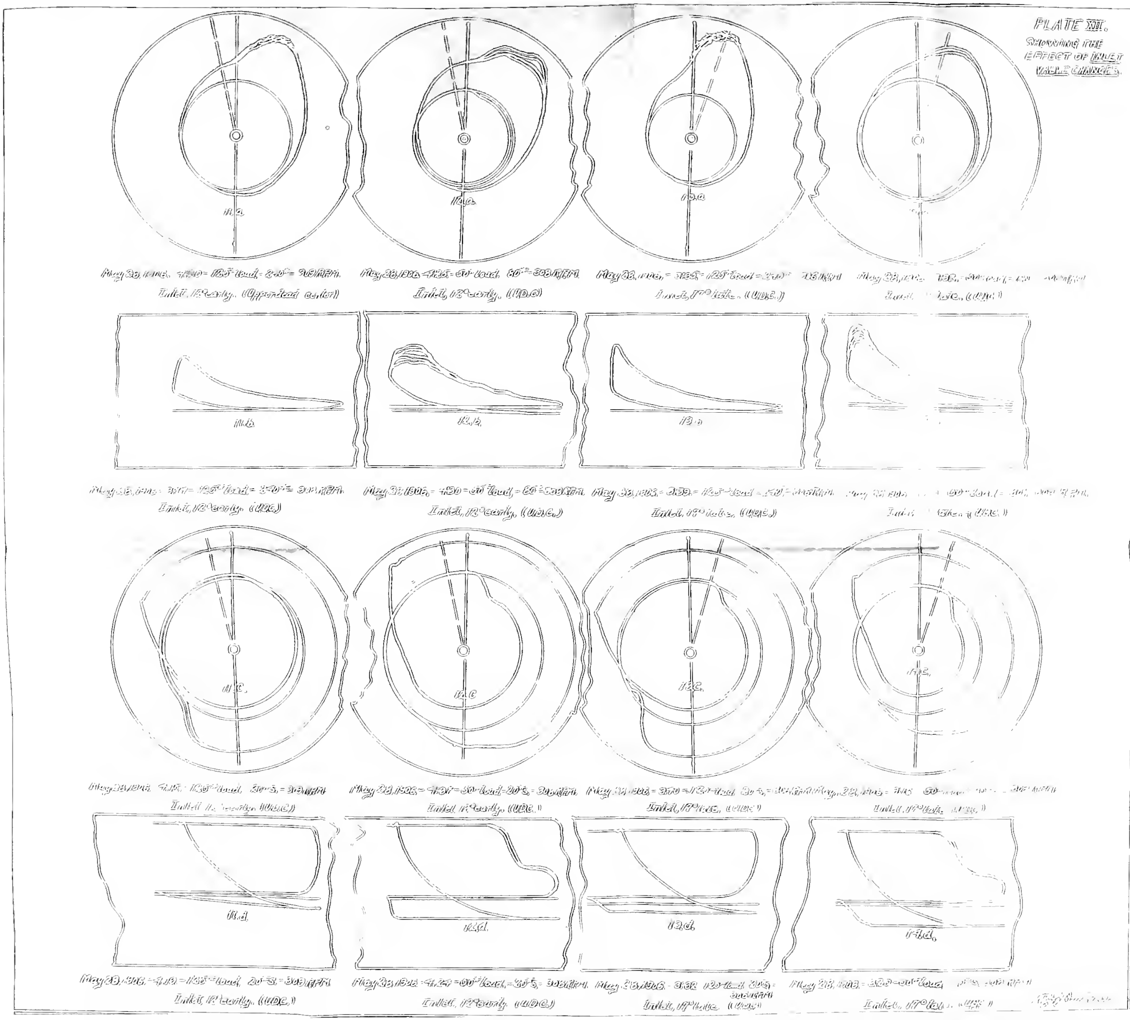
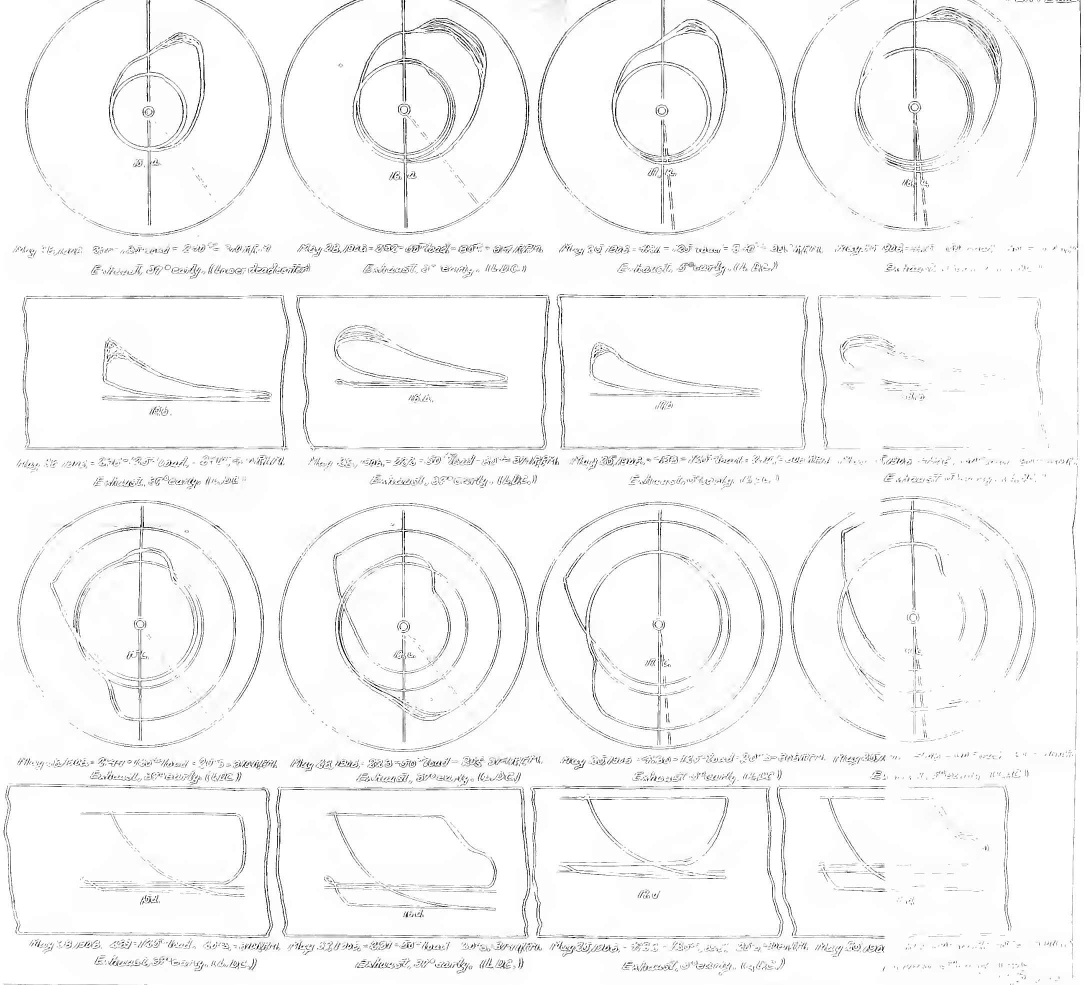


PLATE XII.
SHOWING THE EFFECT OF INLET VALVE CHANGES.
11.a
12.a
13.a
11.b
12.b
13.b
11.c
12.c
13.c
14.c
11.d
12.d
13.d
14.d


E XIV

PLATE XIII.



[illegible]

PLATE XV.

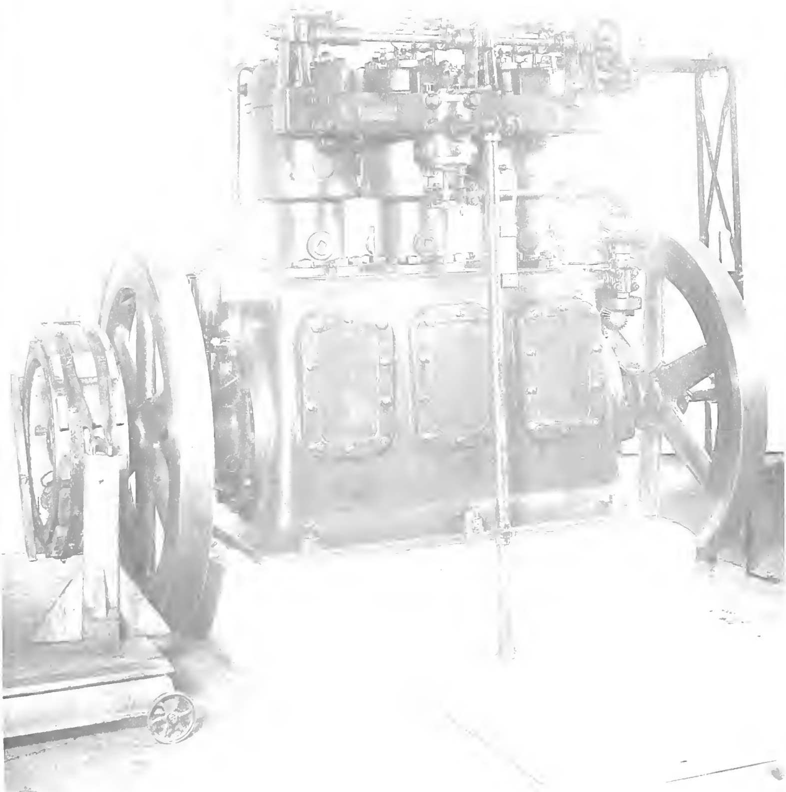


PLATE XVI.

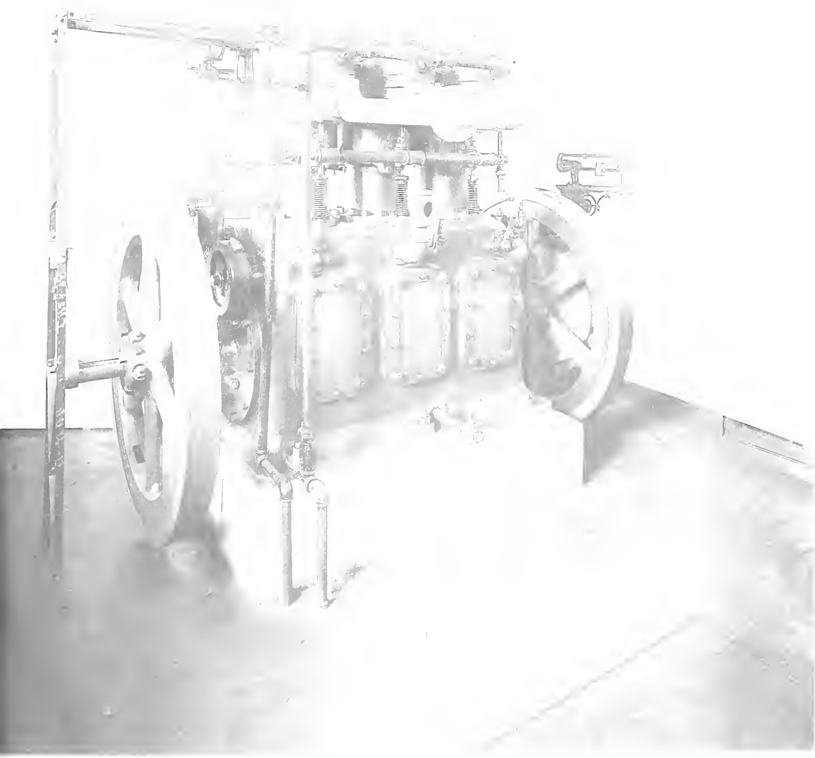


PLATE XVII.


PLATE XIX.

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Plate.